THE EXPERIMENTAL STUDY OF PARTIAL DISCHARGE OF MALAYSIAN BASED PALM OIL

MUHAMAD FIKRI BIN AZIZ

A project report is submitted in partial fulfillment of the requirements for the award of the Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussien Onn Malaysia

JULY, 2012

Dedicated to my beloved father & mother

Aziz bin Abu Bakar & Faridah binti Abdullah

Grandmother

Inchie Yang binti Kani

Siblings

Muhd Farid
Nur Farhana
Nur Arina
Nur Ain Fatihah

My best friend and part of my heart

Salawani binti Noh

And

My Entire friend in MEE programme
For their encouragement

ACKNOWLEDGEMENT

"Praise is to Allah S.W.T, the Most Merciful and the Most Compassionate. Peace is upon him, Muhammad, the messenger of God".

I wish to express my sincere appreciation to my project supervisor, Dr Md Nor Ramdon bin Baharom for all his guidance, encouragement and support in completing the final year project.

I would also like to express my gratitude to all the lectures who have taught me throughout the years of studying in UTHM, thank you for all the knowledge that has been provided.

My gratitude is also extending to my fellow colleagues for sharing their ideas and discussions. Last but not least, I would like to thank my family and loved ones for their motivation and moral support.

ABSTRACT

Insulation is one of the most important parts in a high voltage apparatus, while insulator is a material that resists the flow of the electric current. Most of the transformer used liquid insulating material where its function is to provide electrical insulation and also act as a coolant to prevent overheating of the transformer. Since years ago, petroleum-based mineral oil has been used as a coolant and insulation purpose because of its high electric field strength, low dielectric losses and good long-term performance. There are some reasons that push the search of environmental friendly insulating oils. Conventional transformer insulating materials are usually non-biodegradable. It can contaminate soil and water when serious spill take place. This may disturb the plantation and other lives. In future, this petroleum will be come to an end because it is a non-renewable source. Therefore, this project has been carried out to seek alternatives of vegetables oil that is more environmental friendly. Refined, bleached and deodorized palm oil (RBDPO) has been recognized to be the potential replacement for petroleum-based mineral oil. The main objective of this project is to execute experimental study effect of ageing time and electrical characteristic of Refined, Bleached and Deodorized Palm Oil (RBDPO) by using partial discharge method. Another objective of this project is to make a comparison on electrical properties between new insulating oil, RBDPO with petroleum-based mineral oil. The result indicates the prospect of RBDPO to be further processed to get better dielectric properties and meet all requirements to be used as liquid insulating material. This is because RBDPO has a potential to be a good liquid insulator because of its high breakdown voltage, low dissipation factor and low capacitance when different ageing time were applied.

ABSTRAK

Isolasi adalah salah satu bahagian terpenting dalam peralatan voltan tinggi dan insulator pula adalah bahan bahan yang menolak aliran arus elektrik. Sebahagian besar transformer menggunakan bahan isolasi cair di mana fungsinya adalah untuk memberikan isolasi elektrik dan juga bertindak sebagai pendingin untuk mengelakkan daripada transformer terlalu panas. Sejak dahulu lagi, minyak mineral telah digunakan sebagai bahan penyejuk dan penebatan kerana memiliki sifat dielektrik yang sangat baik, iaitu kekuatan medan elektrik tinggi, kehilangan dielektrik rendah dan prestasi jangka panjang yang bagus. Tetapi masalah yang paling serius adalah membahayakan kesihatan dan mencemarkan alam sekitar. Selain itu, minyak ini juga tidak boleh diperbaharui, maka minyak ini akan habis pada masa depan. Oleh itu, projek ini telah dijalankan untuk mencari alternatif dari minyak sayuran yang lebih mesra alam. Minyak sawit RBDPO telah dikenalpasti mempunyai potensi untuk menjadi pengganti kepada minyak bumi. Objektif utama projek ini adalah untuk mengkaji kesan penuaan dan ciri-ciri electric menggunakan RBDPO menggunakan teknik pengacasan separa.Objektif sampingan pula ialah membuat pembandingan ciri-ciri elektrik dengan minyak berasas kan petroleum. Beberapa eksperimen telah dilakukan untuk mengetahui pengaruh masa terhadap voltan tembus, faktor disipasi dan permitivitas relatif minyak. Dari keputusan yang diperoleh, RBDPO menunjukkan potensi untuk menjadi isolator cair yang baik kerana voltan tembus tinggi, faktor disipasi rendah dan kapasiti rendah apabila masa yang berbeza dikenakan.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BDV		Breakdown voltages
BS		British Standard
FTIR		Fourier Transform Infrared Spectrometry
RBDPO		Refined Bleached Deodorize Palm Oil
kV	-	kilovolt
kA	-	Kilo Amperes
pCs	-	PicoCoulomb
m	-	Meter
mm	-	Millimeter

CHAPTER 1

INTRODUCTION

1.0 Background

Insulators are devices that are used on electricity supply networks to support, separate or contain conductors at high voltage. Insulation is one of the most important parts in a high voltage apparatus. The insulator intended to support or separate electrical conductors without passing current through themselves. There are three basics types of electrical insulating, which is solid, liquid and gas. These materials are widely employed in electrical network components such as circuit breakers, transformers, cables and capacitors [1].

Liquid insulation is used for filling transformers, circuit breakers and as impregnants in high voltage cables and capacitors. Insulation plays important parts in electrical system to insulate the potential charge materials with the earthed object (including human). Failure in insulation could cause electrical breakdown or short circuit in which may introduced the risk of faulty/damage to the equipment as well as causing potential danger to the human. In general, insulation can be formed of solid (e.g. glass, porcelain, or composite polymer materials and etc.), gases (i.e. nitrogen and sulphur hexafluoride) and liquid such as mineral oils (e.g. naphthenic oil and paraffinic oil) [2].

There are several requirements for transformer insulating oil, which includes:

- To act as a coolant with the main task of absorbing the heat from the core and winding, then transmitting it to the outer surface of the transformer. At higher temperatures the viscosity of the oil decreases, thus facilitating the circulation of the oil. It is important to keep the pour point low so the oil is capable at any observable flow.

- To insulate different parts at different electrical potential. Oil makes a good contribution to transformer insulation by penetrating into and filling the spaces between wound insulation layers.

- In order to minimize the evaporation losses, the oil volatility should remain low. Oil temperature in service should be maintained below its flash point

The three most important properties of liquid are dielectric strength, dielectric constant and the electrical conductivity. Other important properties include the viscosity, thermal stability, specific gravity and flash point. The important factors that affect the dielectric strength of oil are the presence of fine water and the fibrous impurities. Therefore, when oils are used for providing electrical insulation, the oil should be free from moisture, products of oxidation and other contaminants [3].

Recently, several liquid insulating material has been introduced which are generally organics type and obtained from nature that are biodegradable and friendly to environmental. For instance, the new liquid insulating material includes vegetables oil such as Soya-bean oil, Sunflower oil, Coconut oil, Olive oil and Palm Oil.

Malaysia is one of the countries that have indigenous resource of palm oil. The sample of palm oil produced includes Crude Palm Kernel (CPKO), Crude Palm Oil (CPO), Crude Palm (CP8), Crude Palm (CP10), and Refined Bleached and Deodorized Palm Oil (RBDPO). This type of oils is safe and environmentally

friendly renewable resources. These oils are widely used and have extensive of resources, hence there is then the assurance of sustainability [4, 5].

1.1 Problem Statement

Petroleum-based mineral oils have been used as liquid insulating materials in power transformer and other high voltage apparatus because of its excellent dielectric properties. Now, the existence of mineral oil in the world has been reduced as the time goes by and probably it will not occupy our needs for the next generation [6].

Due to environmental consideration, recently researches have been put in attempt to search the alternatives of liquid insulating materials. There are some reasons that push the search of environmental friendly insulating oils. Conventional transformer insulating materials are usually non-biodegradable. It can contaminate soil and water when serious spill take place [6, 7].

This may disturb the plantation and other lives. It is important to find alternative oil sources that have similar dielectric characteristics with the existing one and probably can increase the performance of related equipment. Therefore, this oil needs to be replaced with a new type of oil that is friendlier towards the environment.

1.2 Objective

The main objective of this project is to execute experimental study effect of ageing time and electrical characteristic of Refined, Bleached and Deodorized Palm Oil (RBDPO) by using partial discharge method. Another objective of this project is to make a comparison on electrical properties between new insulating oil, RBDPO with petroleum-based mineral oil

1.3 Scope of the Project

The scopes of the project are as the following:

i. Literature Review

Find and understand regarding literature review that covers all study of insulating oil, recent development research, past researcher work and method, characteristics of the liquid insulation, partial discharge method and etc.

ii. Material Sample

Sample used in the experiment is the palm oil and industrial Hyrax transformer oil.

iii. Electrical Properties

The partial discharge (PD) characteristic, which includes PD magnitude and PD numbers.

iv. Data Collected

The data is collected by using partial discharge meter

v. Experimental Area

Partial discharge test is conducted at UTHM High Voltage lab and Polymer and Manufacturing lab to analyze the result based on electrical characteristics and compare result with the international standard such as British Standard.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays making the suitable choice of insulating material and maintaining for high voltage power system equipment is very important for successful operation throughout their lifespan [8]. For applying this it requires knowledge of the material of insulation and how they would be expected to react in various operating environment for example high load operation in power system, especially over long periods .

For high voltage insulators have been developed rapidly by manufacturer like ABB and Siemens since early this century. All of electrical equipment that available in the market rating from small scale of 240V to big scale of 132kV is using insulation in one form or any other to maintain the flow of electrical current in the desired path or circuits [20]. The power system is growing both in size and complexities with the increasing demand of electrical energy. An insulator can be simply described a material that resists the flow of electric current and prevent the flow of current from undesired path. Insulation is also known as dielectric because it's mainly used to control the flow of the current between two conductors [9].

Dielectric can be divided into three major groups such as shown in Figures 2.1 below:

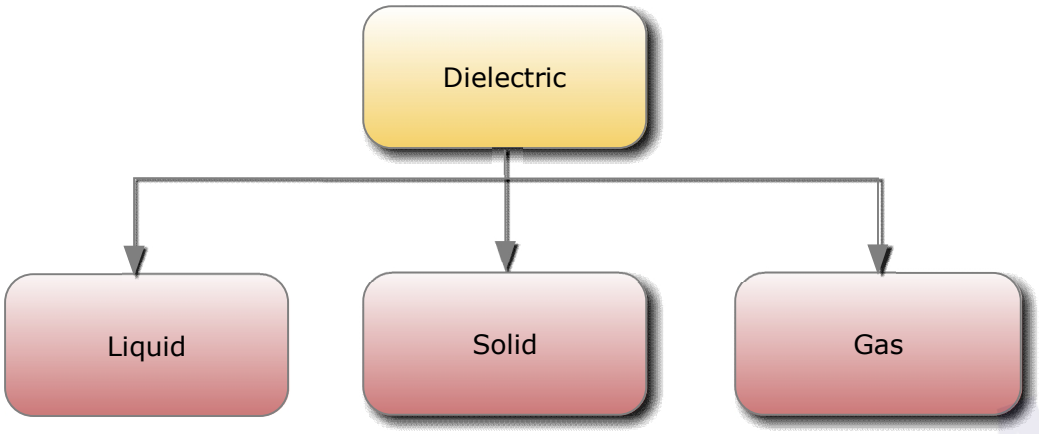


Figure 2.1: Classification of dielectric

Dielectric materials can transmit electrical energy through displacement current but cannot transmit through conduction. Besides that, its primary function depends on its ability to conduct useful electrical current under the conditions of use [10]. Solid dielectric materials are used in all kinds of electrical apparatus and devices to insulate one current carrying part from another when they operate at different voltages. A good dielectric should have low dielectric loss, high mechanical strength, and can be resistant to thermal and chemical deterioration [9]. Solid dielectrics have higher breakdown strength compared to liquid and gases.

The most common dielectrics used are gases. Various phenomena occur in gaseous dielectrics when voltage is applied. When the applied voltage is low, the current flowing will be small throughout the insulation and electrodes that retains the electrical properties. Meanwhile, the current flow will increase sharply when the voltage applied are large. This will conduct an electrical breakdown that produce spark. A short circuit occurs during the spark between electrodes [11].

The gases have wide application in power system to provide insulation to various equipment and substations. The example of gases used are air, oxygen, hydrogen, nitrogen, carbon dioxide and electronegative gases like sulphur

hexafluoride and arcton [12]. The various properties required for providing insulation are:

- High dielectric strength
- Thermal and chemical stability
- Non-inflammability
- High thermal conductivity

Liquid dielectric is very useful as insulating material compared to solids or gases because of their inherent properties. This is because both liquids and solids are denser than gases [9]. Liquids also have same properties like gases which fill the complete volume to be insulated and simultaneously will dissipate heat by convection. Liquids are expected to give a very high dielectric strength. This liquid dielectric mainly as impregnates in high voltage cables and capacitors, and for filling up of transformers and also circuit breaker application.

2.2 Liquid as Insulator

Mineral oils has been the main source as liquid insulating material for decades which are produced from middle range of petroleum-derived distillates. In recent years concern have been take due to polynuclear aromatic hyrocarbons in mineral oils [13]. A substitute to mineral oils other polyster oils have been developed to be used in Europe and other countries as transformer oil. In 1885, the first distribution transformer was built in USA by using air as the dielectric coolant and dry type design. Professor Elihu Thompson who's work for General Motor in Lynn had successfully patented transformer in 1882 which the transformer are smaller and more efficient [14]. In 1892 then General Motor produced his idea after 10 years. After that, the industry then focused on determining the ideal properties of mineral oil for dielectric application and developing process for producing more consistent quality fluid. Figure 2.2 shows the timeline for liquid insulator from 1182 to 1976.

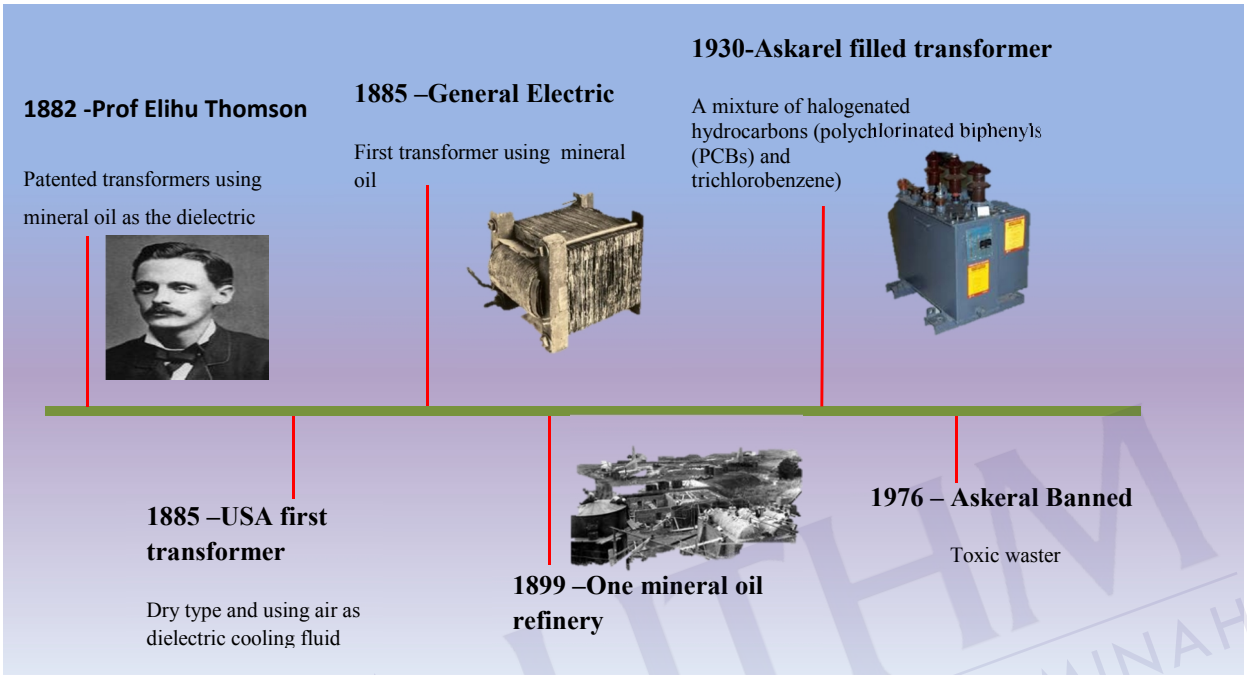


Figure 2.2: Timeline of liquid insulator

As times goes by when personal safety and security become more important for electrical power system equipment especially using mineral oil in power transformer, the usage of alternative insulation fluids is increasing in market [15]. Today people are start to change the view in electrical design equipment analysis by more focusing overall environmental and total life cycle costs beside performance on the equipment. The suggested minimum health and environmental related requirement for applying a material as a dielectric fluid include be essential non-toxic and not be listed as a hazardous material by Environmental Protection Agency (EPA) or Occupational Safety and Health Administration (OSHA). With these trends and concern in mind, the development of potential of non-petroleum, non-hazardous alternative materials with environmental characteristic better than even the highly refined mineral oils. This is because due to its poor biodegradability characteristic to the environment, there is still environmental effect in case of leakage during operation or any accident on the transformer [14, 15].

For improved health and environment safety an additional minimum requirement goals are included:

- Provide a magnitude increase in rate and degree
- Consumed essentially non-toxic material
- Derived from renewable resources of biodegradation

Liquid insulation can be divided into several main groups such as shown in Figure 2.3 below:

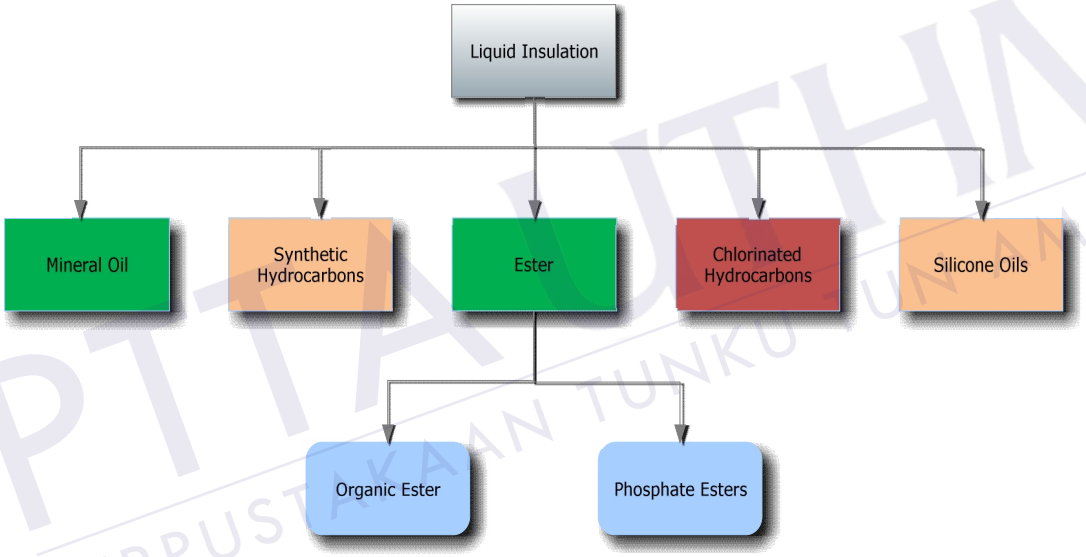


Figure 2.3: Classification of liquid insulation

2.2.1 Mineral Oil

Mineral oil is the most commonly used in dielectric in power apparatus and made of fossil oil. The first mineral oil is used in 1892 by General Electric for transformer that been designed by Prof Elihu Thomson. In early 1899, the usage of the mineral oil as liquid dielectric has been broad because of the development in mineral oil. The usage of mineral oil is more popular than ester that time because the inferior oxygen stability and high pour point, permittivity, and viscosity values. Until today, mineral oils are used for liquid filled transformer as the insulating liquid [13, 14]. When in service, the mineral oil liquid in a transformer undergo a constant heat produce by

the operation of the transformer temperatures about 95 °C and consequently it degradation because of ageing process [16].Figure 2.4 shows degradation of insulation .The mineral oil becomes darker due to the formation of acids and resins or sludge in the liquids. Exposing transformer parts to acids for a long time can cause corrosive to the solid insulating material and metal parts in the transformer. Beside that sludge that deposit inside the transformer core reduces the circulation of the oil and thus its heat transfer capability decreased gradually with time. This will effect on performance of transformer [17]. This is based on the specification for testing transformer oils as given in IS 1866 (1983) IEC 296 (1969) and IEC 474 (1974).

Figure 2.4: Degradation of oil insulation from left to right

Mineral oil consists of 14% hydrogen, 84% carbon in various structure and 1-3% sulphur oxygen-nitrogen call heteatoms [13].

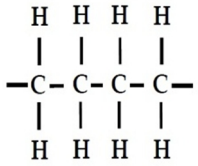
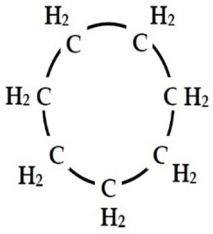
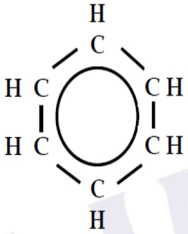
There are two types of mineral oil, the first one us crude mineral oil and the second is refining mineral oil, such as shown in Figure 2.5 below.

Figure 2.5: Classification of mineral oil

The aim for refining mineral oil is to remove or reduce waxes, sulphur, nitrogen and oxygen-compound and the aromatic hydrocarbon [13, 19]. The mineral

oil after refining process has good insulation properties. The basic refining process comprises of a vacuum distillation unit where several step are followed such as such as selective solvent extraction, sulphuric acid extraction, earth filtration, hydrogenation, re-distillation, filtration, and dehydration [16].Table 2.1 below show the main type of mineral oil.

Table 2.1: Main type of mineral oil [6]

Paraffin	Naphthenic	Aromatic
		
Methane (CH4) is a gas, normal butane (C4H10), and isobutene	It has ring structures with six carbon atoms or fourteen Carbon atoms	It has ring structures with six carbon atoms or fourteen Carbon atoms

Generally, liquid insulation is divided into three types of characteristic, which are Electrical, Chemical and Physical properties. The electrical characteristic of liquid insulation is studied in detail. Several of the electrical properties, such as dissipation factor, resistivity and permittivity are tested [9]. The physical and electrical properties of the transformer oil are given in table 2.2

Table 2.2: Dielectric properties of mineral oil [7]

Property	Mineral Oil
Relative Permittivity, 50 Hz	2.2-2.3
Breakdown Strength at 2 0℃	18Kv/mm
Tan δ, 50 Hz	2.5×10^{-4}
Resistivity	10^{13}-10^{14}
Maximum permissible water content (ppm)	50
Acid value	NIL
Specific gravity at 20℃	0.89

2.2.2 Ester oil

Easter are broad class of organic compound and available either as natural agricultural products or chemically synthesized from organic precursor in other word natural ester or synthetic ester [14, 20]. Natural ester appears as saturated and single, double and triple unsaturated fatty acids. The difference between saturated and unsaturated acid is saturated acid is more chemically stable than unsaturated acid but disadvantage in high viscosity. Esters with high percentage of single unsaturated acid have proven more useful for insulating liquids. Although past application implement natural ester in capacitor show potential, but its susceptibility to oxidation became the primary obstacle in using as liquid insulation. However modern transformer design practice along with suitable additives and minor design modification, compensate for this characteristic [13, 14, 22].From Figure 2.6 below shows the structure and bonding for vegetable oil (triglyceride).

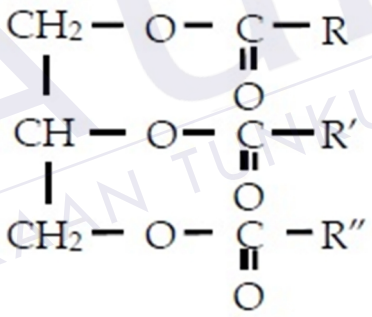


Figure 2.6 : Structure of vegetable oil (triglyceride) [20,21]

Synthetic acid most commonly synthetic polyol ester (POE), have suitable dielectric properties and are significantly more biodegradable if compare to mineral oil or high molecular weight hydrocarbons (HMWH) [14].It's made of an acid and alcohol. The characteristic of the liquid insulation can be modified due to differ with their base materials and viscosity of synthetic ester is twice higher than viscosity of mineral oil. Synthetic ester liquid MIDEL 7131 are used in transformer are carbon acid ester origin from M&I company [13, 14].From Figure 2.7 shows the structure and bonding for synthetic polyol ester.

REFERENCES

[1] J.S.T Looms, 1998, "*Insulation for High Voltage*", Peter Peregrinus Ltd, London, United Kingdom

[2] Patrick MC Shane, 2002, "*Vegetable-Oil-Based Dielectric Coolant*", IEEE Industry Applications Magazine, pp 35-41

[3] Herbert G. Erdman, 1988, *Electrical Insulating Oil*, ASTM International, Ann Arbor, Michigan

[4] Lim Chin Haw, Elias Salleh, Philip Jones, 2006, "*Renewable Energy Policy and Initiatives in Malaysia*", ALAM CIPTA, Intl. J. on Sustainable Tropical Design Research & Practice, Vol. 1 (Issue 1) December 2006: pp. 33-40

[5] U. U Abdullahi, *S* M Bashi, Robia Yunus, Mohibullah, Hj.An1ir Nurdin (2004), "*The Potentials of Palm Oil as a Dielectric Fluid"*, National Power & Energy Conference (PECon) 2004 Proceedings, Kuala Lumpur, Malaysia

[6] Suwarno Aditama ,2005; "*Dielectric Properties of Palm Oils as Liquid Insulating Materials: Effects of Fat Content*". Department of Electrical Engineering, Bandung Institute of Technology, Jl. Ganesha 10 Bandung 40132, Indonesia. Proceedings of 2005 lnternational Symposium on Electrical Insulating Materials, June 5-9, 2005, Kitakyushu, Japan

[7] Suwarno, F. Stitinjak, Ichwan Suhardi, Lufti Imsak, 2003,. "*Study on Characteristic of Palm Oil and it's Derivative as Liquid Insulating Materials*". Department of Electrical Engineering, Bandung Institute of Technology, Bandung, Indonesia. Proceed of the 7th International Conference on Properties and Applications of Dielectric Materials, June 1-5 2003, Nagoya

[8] JP Holtzhausen, High Voltage Insulator, IDC Technologies [Online], Available: http://www.idconline.com/technical_references/pdfs/electrical_engineering/highvoltage.pdf [2011,November 20]

[9] Naidu, M.S. & Kamaraju, V. 2nd ed. 1995*, "High Voltage Engineering"*, Tata McGRAW-Hill, New Delhi

[10] Kai Zhou,Steven A.Boggs, S.Pamir Alpay ,2008, "*Finite Element Modeling of Effective Dielectric Response and Dielectric Tunability in Ferroelectric Composite Materials*" Institute of Material Science, University of Connecticut 97 North Eagleville Road Storrs, CT, 06269-3136 USA. 2008 Annual Report Conference on Electrical Insulation Dielectric Phenomena.

[11] Hae-Eun Jung,Jae-hun Yun, Seong-Hwa Kang, Kyu-Boek Cho,Kee-Joe Lim ,2008, "*Analysis of AC Breakdown of Composite-Insulation depending on Gas Pressure and Solid Insulation Thickness*" Dept. of Electrical and Computer Eng., Chungbuk National University, Korea, Korea Atomic Energy Research Institute,Dept. of Fire Prevention and Safety Eng., Chungcheong University, Korea, Dept. of Electrical Eng., Hanseo University. 2008 International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24, 2008.

[12] C.L Wadhwa, 2007, "*High Voltage Engineering",* NEW AGE INTERNATIONAL (P) LIMITED, PUBLISHERS, New Delhi, India.

[13] Lance R. Lewand. "*Natural Ester as Dielectric Fluid, Chemist's Perspective", Neta World,* pp 1-4, 2004.

[14] Patrick MC Shane, 2002, "*Vegetable-Oil-Based Dielectric Coolant*", IEEE Industry Applications Magazine, pp 35-41.

[15] T.V. Oommen,2002, "*Vegetable Oils for Liquid-Filled Transformers*" , IEEE Electrical Insulation Magazine ,pp 6-11

[16] Marius-Constantin O.S. Popescu, Nikos E. Mastorakis, Liliana N. Popescu-Perescu (2009) "*Modeling of Oil-filled Transformer*" International Journal of Mathematical Models and Methods in Applied Sciences.

[17] Myers, S.D., Kelly, J.J. and Parrish, R.H., "*A Guide toTransformer Maintenance, Transformer Maintenance Institute*", Division of S.D. Myers, Tallmadge, OHUSA.

[18] V Kulkarni & S.A Khaparde, 2004, "*Transformer Engineering*", Marcel Dexter Inc, Mumbai India.

[19] Martin J. Heathcote, CEng, FIEE, 1998, "*J&P Transformer Book*", 12nd edition, Newnes imprint, London, England.

[20] Maria Augusta G.Martins, 2010, "*Vegetable Oils, an Alternative to Mineral Oil for Power Transformers—Experimental Study of Paper Aging in Vegetable Oil versus Mineral Oil*", IEEE Electrical Insulation Magazine, pp 7-13.

[21] C.Patrick McShane, (1999), "*Natural and Synthetic Ester Dielectric Fluids: Their Relative Environmental, Fire Safety, and Electrical Performance*",Cooper Power Systems,Waukesha.

[22] Dieter Dohnal & Rainer Frotscher, "*Importance Of Alternative Insulating Liquids In Power Transformer And Tap Changer"*, Maschinenfabrik Reinhausen GmbH Falkensteinstr, Regensburg, Germany, 2010.

[23] David A. Nattrass, 1993 "*Partial discharge. XVII. The early history of partial discharge research*" IEEE Electrical Insulation Magazine, pp 27-31.

[24] Naidu, M.S. & Kamaraju, V. 2nd ed. 1995, "*High Voltage Engineering"*, Tata McGRAW-Hill, New Delhi.

[25] James,R.E. & Su,Q. 2008, "*Condition Assessment of High Voltage Insulation: In Power System Equipment"*. Institute of Engineering and Technology, London.

[26] S.M Rowland, "*Breakdown in Gaseous, Solid and Liquid Dielectrics"*, MSc. Lecture Note, The University of Manchester, 2006

[27] Subir Ray, 2004 "*Introduction to High Voltage*",Prentice Hall of India, New Delhi.

[28] Stanley Whitehead , "*Dielectric Breakdown of Solids*" Clarendon Press, California.

[29] Mazen Abdel Salam,Hussein Anis, Ahdab El-Morshedy,Roshdy Radwan (2000) "*High Voltage Engineering Theory and Practice*" Marcel Dekker Inc, New York.

[30] Abdul Rajab, Suwarno, Aminuddin, "*Properties of RBDPO Oleum as A Candidate of Palm Based-Transformer Insulating Liquid*", 2009 IEEE

[31] Massimo Pompili "*Partial Discharge Measurements in Dielectric Liquids"*2008 IEEE

[32] R. Eberhardt, H. M. Muhr, W. Lick, B. Wieser "*Partial discharge behaviour of an alternative insulating liquid compared to mineral oil"*, 2010 IEEE